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Effects of Different Rates of Potassium Application on Growth and Yield of Soybean

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ABSTRACT: Soybean is an important legume crop valued for its high protein and oil content, but its productivity is often limited by poor soil fertility and environmental stresses. This study aimed to determine the optimum potassium application rate for improving soybean growth and yield under the agroecological conditions of Kabul, Afghanistan. A field experiment was conducted during the 2025 growing season at the Research Farm of the Faculty of Agriculture, Kabul University, using a randomized complete block design with five potassium levels (0, 25, 50, 75, and 100 kg ha^{-1}) and three replications. Standard agronomic practices were applied uniformly throughout the experiment. Data were collected on plant height, branches per plant, pods per plant, total seeds per plant, 100-seed weight, and grain yield, and analysed using STAR software with the least significant difference test at the 5% probability level. Potassium application had no significant effect on vegetative growth traits, including plant height and number of branches per plant. However, it significantly improved yield components and grain yield. The application of 75 kg K ha^{-1} produced the highest number of pods per plant, greatest 100-seed weight, and maximum grain yield, whereas increasing the rate to 100 kg K ha^{-1} resulted in reduced yield. The findings indicate that potassium application enhances soybean productivity primarily through improved yield components rather than vegetative growth. It is concluded that 75 kg K ha^{-1} is the optimum potassium rate for maximizing soybean yield under the agroecological conditions of Kabul, Afghanistan.

KEYWORDS: Nutrient management, Soybean (Glycine max), Potassium fertilization, Yield components.

INTRODUCTION

Soybean (*Glycine max* [L.] Merr.) is one of the most important grain legumes worldwide and serves as a major source of plant-based protein and edible oil for human consumption, livestock feed, and industrial applications. Increasing global demand for soybean products has created a need to enhance soybean productivity and sustainability across diverse agroecological environments. However, achieving high and stable soybean yields remains challenging due to limitations in nutrient availability and increasing environmental stresses, including drought, salinity, flooding, and declining soil fertility. These constraints are becoming more pronounced under changing climatic conditions, which are characterized by irregular rainfall patterns, rising temperatures, and increased occurrence of extreme weather events (Rajanna et al., 2022; Nader et al., 2024).

Efficient nutrient management is a key strategy for improving soybean growth, productivity, and resilience to environmental stresses. Balanced fertilization with essential nutrients, particularly nitrogen and phosphorus, has been shown to enhance vegetative development, nodulation, nutrient uptake, seed yield, and seed quality. Nget et al. (2022) reported that the application of different nitrogen and phosphorus fertilizer sources significantly improved soybean yield and protein content compared with unfertilized treatments. Similarly, Bradyrhizobium inoculation combined with adequate phosphorus supply enhanced nodulation, phosphorus-use efficiency, economic returns, and grain yield (Mirriam et al., 2022; Szpunar-Krok et al., 2023). These findings demonstrate the importance of appropriate nutrient management in achieving sustainable soybean production.

Among the essential plant nutrients, potassium (K) plays a critical role in soybean growth, development, and yield formation. Potassium is involved in several physiological and biochemical processes, including enzyme activation, photosynthesis, stomatal regulation, osmoregulation, protein synthesis, carbohydrate transport, and maintenance of cellular membrane stability. Adequate potassium nutrition improves water relations, nutrient uptake, and plant tolerance to various abiotic stresses. Because soybean has a relatively high potassium requirement, insufficient K availability can adversely affect reproductive development, seed filling, and final grain yield.

The role of potassium becomes particularly important under stressful environmental conditions. Drought stress is one of the major factors limiting soybean productivity, especially during pod formation and seed development stages. Steiner et al. (2022) reported that adequate potassium application improved leaf water status, enhanced membrane stability, reduced leaf senescence and pod abortion, and mitigated drought-induced yield losses in soybean. Similarly, Nader et al. (2024) found that microbial inoculation improved nutrient uptake, nodulation, growth, and yield performance under drought conditions. Nawaz et al. (2023) also demonstrated that combining biochar with plant growth-promoting bacteria enhanced photosynthetic activity, antioxidant defense mechanisms, and grain yield under drought stress. These studies indicate that improved nutrient management can enhance soybean adaptation to unfavorable environmental conditions.

Potassium also contributes to soybean tolerance under other stress environments. Mamun et al. (2022) reported that split potassium application improved grain yield, nutrient uptake, seed quality, and germination characteristics under waterlogged conditions. Furthermore, Sarioğlu (2025) demonstrated that potassium application, particularly when combined with Bradyrhizobium japonicum, enhanced antioxidant activity, improved leaf water status, reduced oxidative stress, and supported soil microbial activity under saline conditions. Therefore, potassium management represents an important approach for maintaining soybean productivity under diverse environmental stresses.

Beyond stress tolerance, potassium directly influences soybean yield components and seed quality. Potassium availability affects seed composition, including protein, amino acid, oil, sugar, and mineral concentrations (Liu et al., 2022). Appropriate potassium fertilization has been reported to increase soybean yield depending on application rate, soil conditions, and fertilizer source (de Oliveira et al., 2022). However, excessive potassium application may negatively affect nutrient balance by influencing the uptake of other essential elements such as calcium, magnesium, boron, and iron, particularly in soils with low nutrient-buffering capacity (Volf et al., 2022). Therefore, identifying the optimum potassium rate is necessary to maximize soybean productivity while maintaining nutrient balance and fertilizer-use efficiency.

Recent studies have emphasized the importance of improving potassium availability through integrated soil fertility management. Xiu et al. (2025) reported that biochar application increased soil available potassium and enhanced soybean potassium uptake by improving soil chemical properties and nutrient retention. Likewise, Rajanna et al. (2022) showed that soil amendments improving moisture conservation and nutrient availability contributed to greater soybean productivity and water-use efficiency under water-limited conditions. These findings highlight the need for site-specific potassium management strategies to achieve sustainable soybean production.

Although the importance of potassium in soybean production is well established, the optimum potassium requirement varies considerably depending on soil properties, climatic conditions, and crop management practices. In Afghanistan, particularly under the agroecological conditions of Kabul, information regarding potassium requirements for soybean production remains limited. The lack of locally validated potassium recommendations creates uncertainty regarding the appropriate fertilizer rate needed to maximize soybean yield and nutrient-use efficiency. Excessive potassium application may increase production costs and disturb nutrient interactions, whereas insufficient potassium supply may restrict yield potential.

Therefore, location-specific evaluation of potassium application rates is essential for developing effective fertilizer recommendations for soybean production in Kabul. The present study was conducted to evaluate the effects of different potassium levels on soybean growth and yield components and to determine the optimum potassium rate for maximizing soybean productivity under the agroecological conditions of Kabul, Afghanistan.

The specific objectives of this study were to:

- evaluate the effect of different potassium application rates on soybean growth characteristics;
- determine the influence of potassium levels on soybean yield components and grain yield; and
- identify the optimum potassium rate for improving soybean productivity under Kabul conditions.

It was hypothesized that appropriate potassium application would enhance soybean yield components and grain yield, while excessive or insufficient potassium supply would reduce crop performance.

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MATERIALS AND METHODS

Study Design and Experimental Site

A field experiment was conducted during the 2025 cropping season at two experimental fields located at the Research Farm of the Faculty of Agriculture, Kabul University, Kabul, Afghanistan. The experiment was designed to evaluate the effect of different potassium application rates on soybean growth, yield components, and grain yield. The soil at the experimental site was sandy loam in texture with slightly alkaline conditions (pH 7.8). The soil contained 0.9% organic matter, 0.03% total nitrogen, and 1.83 ppm available phosphorus.

Experimental Design and Treatments

The experiment was established using a randomized complete block design (RCBD) with five potassium treatments and three replications. The treatments consisted of:

- T_1: Control (0 kg K ha^{-1})
- T_2: 25 kg K ha^{-1}
- T_3: 50 kg K ha^{-1}
- T_4: 75 kg K ha^{-1}
- T_5: 100 kg K ha^{-1}

Each experimental plot measured 2 m × 2 m. Soybean was planted with a spacing of 30 cm between rows and 10 cm between plants, using a seed rate of 25 kg ha^{-1}. The soybean variety was sown on 13 May 2025.

Fertilizer Application and Crop Management

Potassium was applied in the form of potassium sulfate (K_2SO_4, containing 50% K_2O) during land preparation according to the assigned treatment levels. Recommended doses of nitrogen fertilizer were applied uniformly to all plots in two split applications. Diammonium phosphate (DAP) and farmyard manure (FYM) were also applied uniformly during land preparation according to recommended practices.

All plots received similar crop management practices throughout the growing season. Irrigation, weed control, thinning, and other standard agronomic operations were carried out as required to maintain optimal crop growth. The crop was harvested at physiological maturity in two pickings.

Data Collection and Measurement Procedures

Growth, yield component, and yield data were collected from each plot. Growth parameters included plant height, number of branches per plant, and number of leaves per plant. Yield attributes recorded were pods per plant, seeds per plant, and 100-seed weight. Grain yield was determined on a plot basis and converted to kilograms per hectare (kg ha^{-1}).

Statistical Analysis

The collected data were subjected to statistical analysis using Statistical Tools for Agricultural Research (STAR) software. Analysis of variance was performed to determine the significance of treatment effects. Differences among treatment means were compared using the least significant difference (LSD) test at a probability level of $p \leq 0.05$.

RESULTS

Plant Height

Analysis of variance showed that potassium application rates did not have a significant effect on soybean plant height at the 5% probability level ($p > 0.05$). Although differences were observed among treatments, they were not statistically significant. The highest plant height was recorded with the application of 75 kg K ha^{-1} at the first location and 100 kg K ha^{-1} at the second location (Table 1).

Table 1. Effect of potassium application rates on soybean plant height

Treatments	Plant height (cm) 1	Plant height (cm) 2
Control	34.00	33.53
25 kg ha^{-1} K	34.27	29.73
50 kg ha^{-1} K	32.13	30.27

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75kg ha⁻¹ K	35.27	34.33
100 kg ha⁻¹ K	32.93	35.20
CV (%)	7.77	
ANOVA	NS	

NS = Not significant.

Number of Branches per Plant

The analysis of variance indicated that potassium application had no significant effect on the number of branches per soybean plant at the 5% probability level ($p > 0.05$). The highest number of branches was recorded with the application of 75 kg K ha^{-1} in both experimental locations, while the lowest values were observed under the control and lower potassium treatments (Table 2).

Table 2. Effect of potassium application rates on the number of branches per soybean plant

Treatments	Number of Branches 1	Number of Branches 2
Control	12.00	11.93
25 kg ha⁻¹ K	13.73	9.73
50 kg ha⁻¹ K	12.67	11.93
75kg ha⁻¹ K	14.40	14.00
100 kg ha⁻¹ K	12.33	13.40
CV (%)	13.38	
ANOVA	NS	

NS = Not significant.

Number of Pods per Plant

Potassium application significantly affected the number of pods per plant ($p \leq 0.05$). The highest number of pods per plant was recorded with the application of 75 kg K ha^{-1} (32.33 pods plant^{-1}), whereas the lowest value was observed with 100 kg K ha^{-1} (25.57 pods plant^{-1}). Treatment means differed significantly according to the least significant difference test (LSD = 4.25) (Table 3).

Table 3. Effect of potassium application rates on pods per soybean plant

Treatments	Number of Pods per plant
Control	26.03 b
25 kg ha⁻¹ K	26.77 b
50 kg ha⁻¹ K	28.50 ab
75kg ha⁻¹ K	32.33 a
100 kg ha⁻¹ K	25.57 b
CV (%)	12.48
ANOVA	*
LSD	4.25

*NS = Not significant; * = Significant at $p \leq 0.05$.*

Number of Seeds per plant

The number of seeds per plant was significantly influenced by potassium application ($p \leq 0.05$). The highest number of seeds per plant was obtained with 75 kg K ha^{-1} (83.47), while the lowest value was recorded with 100 kg K ha^{-1} (61.50). Treatment differences were significant according to the LSD test (LSD = 10.31) (Table 4).

Table 4. Effect of potassium application rates on seeds per plant

Treatments	Number of seed per plant
Control	63.90 b
25 kg ha^{-1} K	63.90 b
50 kg ha^{-1} K	68.70 b
75kg ha^{-1} K	83.47 a
100 kg ha^{-1} K	61.50 b
CV (%)	12.34
ANOVA	*
LSD (0.05)	10.31

*NS = Not significant; * = Significant at p ≤ 0.05.*

Hundred-Seed Weight

Potassium application significantly affected 100-seed weight at the 5% probability level ($p \leq 0.05$). The highest 100-seed weight was recorded with 75 kg K ha^{-1} in both locations (20.33 g and 19.00 g, respectively). The lowest values were recorded with 100 kg K ha^{-1} at the first location (17.00 g) and 25 kg K ha^{-1} at the second location (14.67 g). The coefficient of variation was 4.74%, and the LSD value was 1.39 (Table 5).

Table 5. Effect of potassium application rates on 100-seed weight of soybean

Treatments	100-seed weight (g) 1	100-seed weight (g) 2
Control	18.00 bA	15.00 bB
25 kg ha^{-1} K	18.33 bA	14.67 bB
50 kg ha^{-1} K	16.00 cA	16.00 bA
75kg ha^{-1} K	20.33 aA	19.00 aA
100 kg ha^{-1} K	17.00 bcA	15.66 bA
CV (%)	4.74	
ANOVA	*	
LSD (0.05)	1.39	

*NS = Not significant; * = Significant at p ≤ 0.05.*

Grain Yield

Potassium application significantly influenced soybean grain yield ($p \leq 0.05$). The highest grain yield was obtained with the application of 75 kg K ha^{-1} (905.17 kg ha^{-1}), while the lowest yield was recorded with 100 kg K ha^{-1} (669.17 kg ha^{-1}). The coefficient of variation was 8.53%, and treatment differences were significant according to the LSD test (LSD = 77.12) (Table 6).

Table 6. Effect of potassium application rates on soybean grain yield

Treatments	Grain yield (kg ha^{-1})
Control	694.00 b
25 kg ha^{-1} K	700.83 b
50 kg ha^{-1} K	722.50 b
75kg ha^{-1} K	905.17 a
100 kg ha^{-1} K	669.17 b
CV (%)	8.53
ANOVA	*
LSD (0.05)	77.12

*NS = Not significant; * = Significant at p ≤ 0.05.*

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DISCUSSION

Potassium is an essential nutrient involved in numerous physiological processes that regulate plant growth, reproductive development, and yield formation. The present study evaluated soybean responses to different potassium application rates under the agroecological conditions of Kabul, Afghanistan. The findings demonstrated that potassium application had limited influence on vegetative growth parameters but significantly improved major yield components and grain yield, with 75 kg K ha^{-1} producing the most favorable overall response.

Effect of Potassium on Growth Parameters

The results showed that potassium application did not significantly affect soybean plant height or number of branches per plant. Although the highest values for these traits were generally recorded with moderate to high potassium application, the differences among treatments were statistically non-significant. This suggests that vegetative growth was not strongly limited by potassium availability under the conditions of the experiment.

Similar findings were reported by Volf et al. (2022), who observed that increasing potassium rates influenced soybean nutrient uptake but did not consistently improve vegetative growth characteristics. Likewise, Liu et al. (2022) reported that potassium nutrition had a stronger influence on seed quality and reproductive performance than on vegetative growth, with responses varying among soybean genotypes. These results indicate that soybean vegetative traits may be controlled more strongly by genetic characteristics, environmental conditions, and the availability of other essential nutrients than by potassium application alone.

However, Kumari et al. (2023) reported increased soybean growth when potassium was applied together with phosphorus and recommended fertilizer management. This difference suggests that potassium may produce stronger effects when combined with balanced nutrient supply rather than being applied as a single nutrient. Therefore, the absence of significant responses in plant height and branching in the present study may be associated with adequate existing nutrient availability or the influence of other growth-limiting factors.

Effect of Potassium on Yield Components

Unlike vegetative traits, potassium significantly influenced soybean reproductive characteristics, including pods per plant, seeds per plant, and 100-seed weight. The highest values of these yield components were recorded with 75 kg K ha^{-1}, indicating that an adequate potassium supply supported reproductive development and seed formation.

The increase in pods per plant with moderate potassium application agrees with de Oliveira et al. (2022), who reported that potassium fertilization improved soybean yield components, although the magnitude of response depended on fertilizer rate and soil conditions. Similarly, Mamun et al. (2022) demonstrated that appropriate potassium management enhanced soybean reproductive growth and productivity under different environmental conditions. Potassium contributes to reproductive success by improving photosynthetic activity, assimilate transport, enzyme activation, and water regulation, all of which are important processes during pod formation.

The decline in pod number and grain-related traits at the highest potassium rate (100 kg K ha^{-1}) indicates that excessive potassium application did not provide additional benefits. Similar observations were reported by Volf et al. (2022), who found that increasing potassium rates altered nutrient interactions but did not always result in improved soybean growth or productivity. Excessive potassium supply may affect the balance and uptake of other nutrients, reducing fertilizer-use efficiency.

The improvement in seed number and 100-seed weight under 75 kg K ha^{-1} further demonstrates the importance of maintaining optimum potassium availability during reproductive stages. Adequate potassium enhances the movement of carbohydrates from source tissues to developing seeds, promoting grain filling and seed development. These findings are consistent with de Oliveira et al. (2022) and Mamun et al. (2022), who reported improved soybean seed weight and yield attributes under appropriate potassium management. Liu et al. (2022) also confirmed that potassium nutrition influences important seed characteristics, although responses differ among soybean varieties.

The present study showed that potassium application significantly increased soybean grain yield, with 75 kg K ha^{-1} producing the highest yield. This indicates that soybean productivity in the study area was improved by correcting potassium availability up to an optimum level. The positive yield response may be attributed to potassium's role in improving photosynthesis, enzyme activity, stomatal regulation, water-use efficiency, and translocation of assimilates toward developing seeds.

The results agree with de Oliveira et al. (2022), who found that potassium fertilization increased soybean yield when applied at suitable rates. Similarly, Mamun et al. (2022) reported that effective potassium management improved soybean yield and seed quality by supporting reproductive development. Kumari et al. (2023) also demonstrated that balanced nutrient management, including potassium application, improved soybean productivity compared with nutrient-deficient conditions.

The findings also support the role of potassium in improving crop performance under stressful environments. Steiner et al. (2022) reported that adequate potassium reduced the negative effects of drought stress by improving plant water status and maintaining physiological activity. Xiu et al. (2025) further showed that improved soil potassium availability enhanced soybean potassium uptake and productivity. These studies collectively confirm that maintaining sufficient potassium availability is essential for achieving stable soybean production.

The reduced yield observed at the highest potassium rate suggests that potassium application beyond the crop requirement does not necessarily increase productivity. Instead, excessive potassium may reduce nutrient-use efficiency and disturb the balance among other essential nutrients. Therefore, the identification of an optimum potassium rate is important for both economic and environmental sustainability.

This study provides valuable information on potassium management for soybean production under the agroecological conditions of Kabul, Afghanistan, where locally developed fertilizer recommendations are limited. The identification of 75 kg K ha^{-1} as the optimum potassium rate provides a practical guideline for improving soybean yield and fertilizer-use efficiency in similar production environments.

A major contribution of this research is the demonstration that potassium primarily influenced yield formation rather than vegetative growth under the tested conditions. This finding improves understanding of soybean nutrient responses and highlights the importance of evaluating fertilizer recommendations based on yield components rather than only plant growth characteristics.

The results have practical implications for farmers and agricultural extension programs by supporting the adoption of balanced potassium fertilization strategies. Applying potassium at the optimum rate may increase soybean productivity while avoiding unnecessary fertilizer costs associated with excessive application.

A strength of this study was the evaluation of multiple potassium application rates under field conditions using a randomized complete block design with replications, allowing reliable comparison among treatments. The study also assessed multiple growth and yield-related parameters, providing a comprehensive evaluation of soybean response to potassium fertilization.

However, one limitation was that the initial soil available potassium level was not measured before planting. Therefore, the relationship between the observed soybean response and the initial potassium status of the soil could not be directly established. In addition, the study was conducted during a single growing season, which limits the ability to fully evaluate seasonal variation in potassium response.

Future studies should include detailed soil fertility assessments, particularly initial available potassium levels, to develop more precise potassium recommendations for soybean production in Afghanistan. Multi-year and multi-location experiments are also needed to evaluate potassium responses under different soil types, climatic conditions, and soybean varieties. Further research should investigate the interaction of potassium with other nutrients, irrigation management, and soil amendments to develop integrated nutrient management strategies for sustainable soybean production.

CONCLUSION

The study demonstrated that potassium application did not significantly affect soybean vegetative growth traits, including plant height and branch number, but significantly improved yield components and grain yield. The application of 75 kg K ha^{-1} resulted in the highest pods per plant, seed number, 100-seed weight, and grain yield, whereas increasing potassium application to 100 kg K ha^{-1} did not improve productivity. Therefore, 75 kg K ha^{-1} was identified as the most effective potassium rate for enhancing soybean yield under the conditions of this study. These findings contribute to improved potassium management recommendations for soybean production in the agroecological conditions of Kabul, Afghanistan.

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